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Goddard Space Flight Center

Limb Gridded Radiance User Guide

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1.0	9 June 2015	DAK	Fixed units for Radiance.

1 Introduction

The Level 1G (L1G) product is a radiance data product derived from measurements by the limb portion of the Ozone Monitoring and Profiling Suite (OMPS) of instruments aboard the Suomi NPP satellite. The product contains a gridded version of limb radiance measurements–the spectral and spatial smile have been removed by interpolating the data onto a regular (but non-uniform) spatial (i.e. altitude)-spectral grid. This is done because often it is more convenient for users to have gridded data than to have to remove the smile themselves.

The goal in this User Guide is to provide users with a basic understand of the instrument and the manner in which the gridded product is derived from the ungridded product. It provides detailed descriptions of the contents of the data files and also include examples (with code listings) for using the data, in particular wavelength and quality flags. This document:

1. Describes the instrument and measurement geometry. (Section 2)
2. Provides an overview of how the L1G product was generated from the non-gridded data. (Section 3)
3. Describes the organization of the orbital HDF5 files which contain the data. (Section 4)
4. Shows how to use the data with particular emphases on the searching for and using the correct wavelengths.
5. Contains several examples, including a typical radiance profile at 305 nm and the detection of the dust cloud injected into the atmosphere by the Chelyabinsk Bolide in February 2013 (Sections 4.7 and 6).

2 The Suomi NPP OMPS Limb Profiler Instrument

Instrument

2.1 Viewing Geometry

The OMPS Limb Profiler instrument measures three geographically distinct, spectrally resolved radiance profiles of the earth's atmosphere by viewing the limb aft of the Suomi NPP Satellite. The measurements within each profile correspond to different tangent point altitudes and are the result of light scattered toward the instrument by the atmosphere at or above that altitude.

The three geographically distinct profiles are achieved because the instrument peers through three collimating slits–left, center, and right–whose tangent points are separated by about 250 km. These three slits are commonly referred to as East, Center, and West because of their relative locations when project onto the earth's surface during much of the day side of the orbit. Figure 1 shows the viewing geometry for one of single LOS of one slit.

The vertical resolution of the instrument is approximately 1 km. The three profiles are measured on the day side of Suomi NPPs polar orbit at approximately 19 second intervals. In nominal earth view mode this allows the instrument to capture about 160 images each orbit with solar zenith angles less than 88 degree. The set of radiance profiles over the same tangent point is referred to as a *scene*. LP measurements cover a wavelength range between 290-1000 nm. The spectral resolution varies from approximately 1.0 nm at 290 nm to approximately 40 nm at 1000 nm.

The light measured at each altitude is spectrally resolved via a prism. The measurements are made with a 2 dimensional CCD: one dimension corresponds to altitude and the other to wavelength. There are no scanning mirrors.

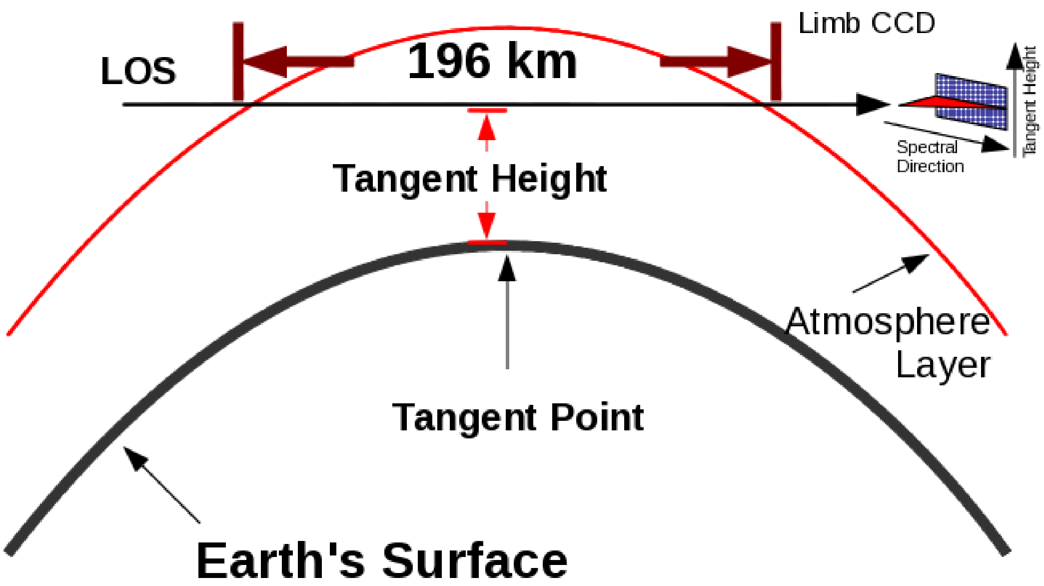

Figure 1: The Line of Sight (LOS) cuts through many layers of the atmosphere although only one layer is illustrated here (in red). This figure shows only a single LOS for a single slit, but the instrument is capable of measure about 100 of them at different angles for each of the three slits. The figure is not to scale–the vertical angle is small and the distance from the instrument to the tangent point (3000km) is large–so the different lines of sight are approximated as parallel and each one provides information about different tangent heights. The vertical width of the 196 km LOS marked in the figure is within 1 km.

fig:ViewGeom

2.2 Source and Target Grids

The raw count pixels in the images are converted to calibrated radiances and are produced in a product referred to as the Level 1B. Optical distortions within the spectrometer result in curvature at the focal plane, sometimes referred as ’smile’. Rows and columns of the CCD are not rows and columns of constant wavelength or altitude. Thus the Level 1B product is not necessarily the most convenient form in which to use the radiance data to retrieve ozone or aerosol profiles. We therefore transform these data to a rectangular wavelength-altitude grid to create the Level 1 gridded (L1G) product described in this document. The source (L1B) and target (L1G) grids are shown in Figure 2.

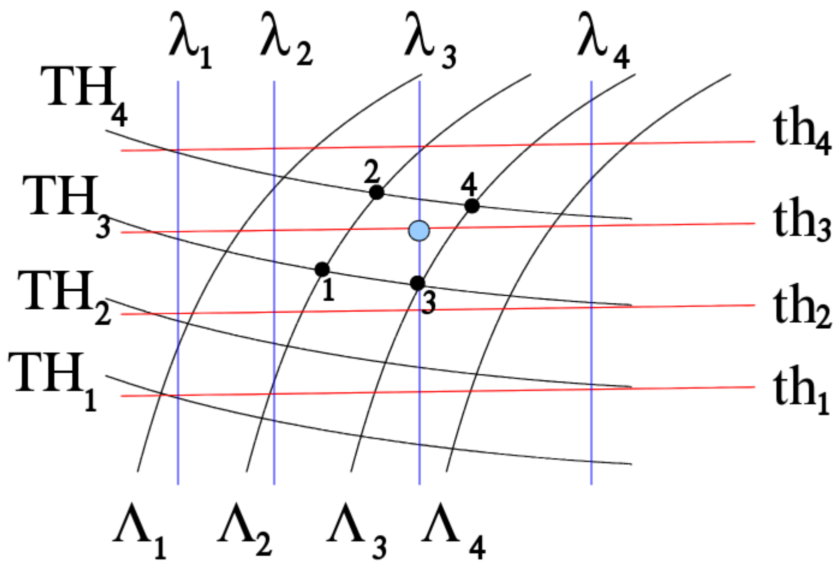

Figure 2: Non-orthogonal and orthogonal grid points. The black lines labeled with capital letters indicate the non-orthogonal lines of constant CCD row and column indexes–TH and Λ are the nominal tangent height and wavelength indexes, respectively. The blue and red lines indicate the orthogonal lines of constant wavelength and tangent height respectively. The blue circle is a target grid point for the L1B product and the black dots (i.e. centers of CCD pixels) are the source data used in the bilinear interpolation. This figure is simplified in that in reality the non-orthogonal constant lines do not necessary cross through the center of neighboring CCD pixels; so, for example, source points 1 and 2 will not quite be at the same wavelength. During processing the calibration table are used which contain the exact wavelength of each CCD pixel. fig:GridPoin

3 The LP-L1G-EV Product Overview and Preliminaries

Generation

The LP-L1G-EV product is formed from calibrated radiances from the Level 1B product which have been subject to a number of processing steps to make the data easier to use. For each measured profile a unified radiance spectrum is provided on an orthogonal, but non-uniform, wavelength-altitude grid in the

LP-L1G-EV product. The non-uniformity means simply that the density of the wavelength grid is higher at the shorter wavelengths than the longer wavelength. Note that this *grid* is a different concept than the one familiar to users of Aura EOS products; in particular the latitude and longitude of the profile *remain the same* as they were in the original data.

The spacing in the altitude direction is nominally a uniform one kilometer with grid points centered at the half kilometer points above 0 (i.e. altitude grid points of 0.5, 1.5, 2.5 km, etc). A more detailed description of this process can be found in the *OMPS Limb Profiler Sensor Data Record (SDR) Algorithm Theoretical Basis Document*.

The instrument can collect about 160 images of usable data on the day side of an orbit. (Often the instrument is run for 180 images per orbit, but the additional 20 tend to be pre- or post-terminator and thus are not useful for ordinary retrievals.) Each image consists of data corresponding to three different tangent points on the earths surface, so a nominal earth view orbit will contain about $3 \times 60 = 180$ usable hyperspectral profiles.

To obtain high dynamic range the instrument measures each profile with images taken at with different aperture sizes via separate optical paths and regions on the CCD sensor. This is complicated by the fact that the satellite does not support sufficient data rate to downlink every illuminated pixel on the CCD. A judicious selection of pixels has been made based on the expected scene intensity profile.

3.1 Getting Data

The version 2 data can be found at this URL: `http://dx.doi.org/10.5067/suomi-npp/omps-limb/l1-ev-grid/data12`

3.2 Product File names

The product file names follow this pattern:

$$\underbrace{\text{OMPS-NPP}}_{\text{Platform}}\_\underbrace{\text{LP-L1G-EV}}_{\text{Product Name}}\_\overbrace{\text{v2.0}}^{\text{Product Version}}\_\underbrace{\text{2014m0128t055729}}_{\text{Data Date}}\_\text{o}\underbrace{\text{11675}}_{\text{Orbit Number}}\_\underbrace{\text{2014m0128t074000}}_{\text{Processing Timestamp}}\text{.h5}$$

3.3 HDF5 File Format

ubsec:HDF5

The data are provided in the HDF5 file format. The HDF5 library is required to read the files. This library is available from The HDF Group (www.hdfgroup.org). In addition to interfaces in C and Fortran, which The HDF Group develops and distributes, there is a high quality interface for Python called H5py distributed independently. These are all open source. The HDF Group also distributes a number of tools for exploring and manipulating HDF5 files. The graphical tool HDFView is highly recommended, especially for those just starting with HDF5 or the OMPS data. The HDF5 library is also incorporated into many common commercial data analysis tools: Matlab, IDL, TecPlot, Mathematica, etc.

The HDF5 file consists of **Dataset**s which is the HDF5 terminology for array and **Groups** which contain datasets and other groups (thus groups behave analogously to folders or directories in your computer's file system). Both the datasets and the groups are given descriptive names. Because the objects are named they can be accessed by name rather than by file offset which is a tremendous advantage afforded by the HDF5 format.

The HDF5 library sheilds the users from needing to understand the byte order of numerical data or the actual layout of the data on disk. The datasets in HDF5 include dimensional and type information and HDF5 library can query the file to determine these which is often necessary for C or Fortran users. The higher level languages (Python, IDL, Matlab, etc.) generally have convenience functions which reduce some of the programming burden. These are recommended for users new to HDF5.

3.4 Non-rectangular (Ragged) Datasets

ec:Nonrect

The **Wavelength**, **Radiance**, and **SNR** datasets are non-rectangular or ragged. This means that the number of valid indexes in the wavelength dimension is less than or equal to the size of that dimension in the HDF5 dataset. This occurs because the number of valid wavelengths can vary from image to image and slit to slit. When a wavelength is 'dropped' from a slit-event, the arrays are 'compacted' in the wavelength dimension to eliminate the gap.

The number of valid wavelength indexes is contained in the dataset NumberOfPrimaryChannels and the valid values have all been 'compacted' into the lowest indexes of the ragged array. Thus a wavelength dimension has a nominal size of 300. If the number of primary channels is 179 then the first (lowest) 179 indexes will contain good data and the remaining 121 will have fill values. The number of valid indexes is recomputed throughout the orbit and can be different for each slit. This can be seen graphically in Figure 3.

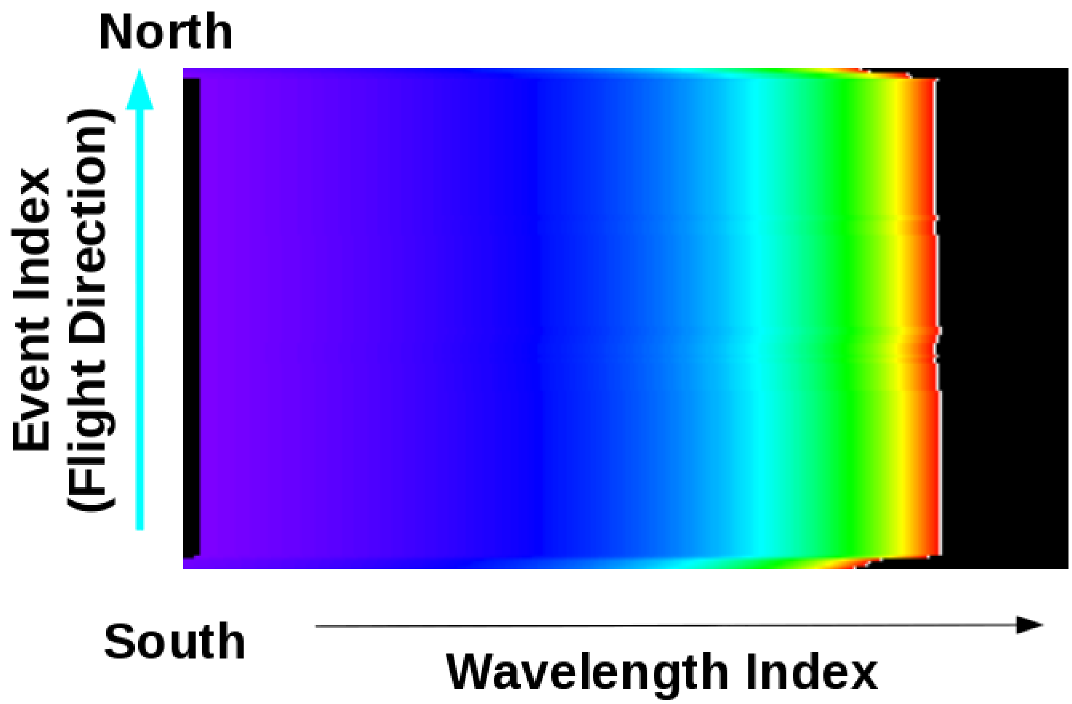

Figure 3: An image of the wavelengths computed in the gridding process for different images during the course of a single orbit for the center slit. Short wavelengths are blue; long ones are red, wavelength increases with index; the black region on the right are fill values (-999.0). The ragged right hand side edge of the red color is due to the varying ability of the algorithm to find the same wavelengths for different measurements. Similarly, several horizontal black bands are measurements for which the algorithm could not place any data onto the grid. The black region on the left hand side are small values of wavelength colored black due to an artifact of the color scale. fig:RaggedWa

The implication of the ragged edge along the wavelength dimension is that software using the L1G data needs to be 'smart' about determining wavelength index. The wavelength index must be determined by searching the wavelength array for each scene processed. This important point is discussed in more detail later in examples in sections 6 and 4.7.

4 Product Details

ctContents

The gridded data product is provided in the HDF5 format which is a very general and flexible file format for numerical data. (See 3.3.)

The hyper-spectral profile data has several basic components, most obviously are the wavelength and corresponding radiance intensity. These are stored in the **Wavelength** and **Radiance** datasets, respectively. Furthermore, because the data are vertical profile data above a particular tangent point on the earth's surface there are also altitude data in the **TangentHeight** dataset and geolocation information for the tangent point itself in the Latitude and Longitude datasets.

The organization of these datasets is detailed in the following sections.

4.1 The Top Level

HDF5 files encourage the organization of data in a hierarchical fashion. The top level contains 4 groups and one dataset as seen in Figure 4.

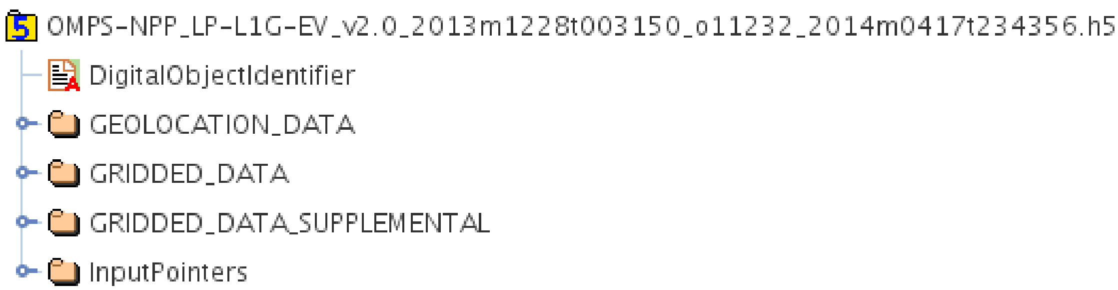

Figure 4: The top level group. TOPLEVEL

The LP-L1G-EV product contains two important groups, the GRIDDED_DATA group and the GEOLOCATION_DATA group. Using the HDFView TreeView window an example of the contents of the GRIDDED_DATA group is shown in Figure 5 and the names of the datasets and their associated data descriptions are in Table 3 for GRIDDED_DATA. The GRIDDED_DATA_SUPPLEMENTAL group will not be described in its entirety because much of it used for internal data processing needs and is expected to be removed in future versions.

4.2 Gridded Data

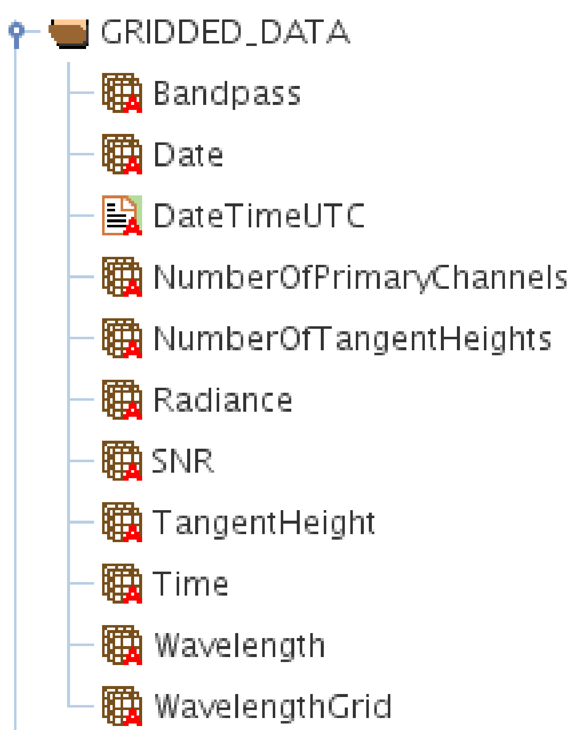

Figure 5: The GRIDDED_DATA group. SDR

4.3 Dimensions

The data are stored as HDF5 datasets, i.e. arrays. The semantics of the dataset dimensions are defined in Table 2 along with a dimension label. These labels are used in Tables 3 and 4 which describe the product's datasets. Neither the label nor the description are stored in the products themselves.

Dimension Label	Description
nTimes	The image dimension. Each index in this dimension corresponds to an image taken at different time. The index is ordered–larger indexes are later in time.
nSlit	The slit dimension. There are three slits and the ordering is left, center right.
nTH	The tangent height dimension. This dimension corresponds to the tangent height of the grid points. Higher indexes correspond to higher altitudes.
nWave	The wavelength dimension. This dimension corresponds to the wavelength of the grid points. The valid indexes are discussed in Section 3.4.

Table 2: Dimension labels and descriptions

tab:dimensio

4.4 Radiances /GRIDDED_DATA/Radiance

:Radiances

The gridded radiances are in the Radiance dataset. This array covers the whole altitude and wavelength range of the instrument, from starting wavelength around 272 nm to an ending one near 1058 nm and in altitude from 0 to 100 km. The measurements from 2 apertures are combined in this array, however even when using both measurements it is not possible to fill in all possible grid points with a reasonable bilinear interpolation of measured data. In Version 2, unlike Version 1, missing grid points are left as fill values. Grid points may be missing because of saturation or because the sample table which controls which pixels are down-linked did not include pixels near enough to a grid point for the bilinear interpolation code to compute it. Figure 6 shows an example of a radiance spectrum of the center slit for one scene.

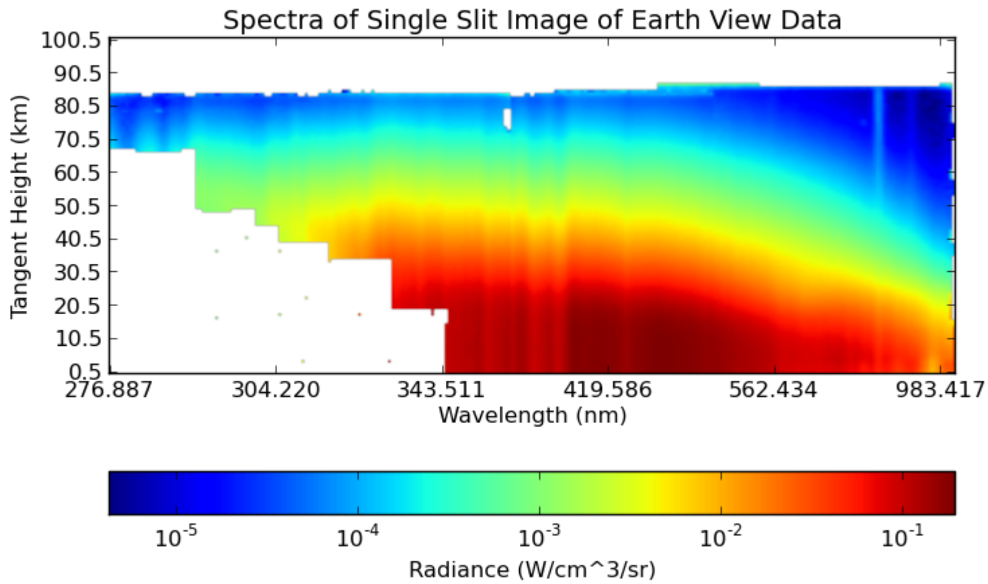

Figure 6: Radiance image for a single limb scene corresponding to the center slit for a single 19s reporting period. The white regions are fill values where there was insufficient ungridded data to interpolate to a grid point. Note that any wavelengths which would have been all fill for all altitudes were removed during the gridding process and hence do not appear in the image. The isolated pixels at short wavelengths and low altitude are real and come from data which were sampled to provide stray light correction. fig:ProfileSp

4.5 Wavelength /GRIDDED_DATA/Wavelength

The **Wavelength** dataset contains the wavelengths for which radiances have been reported out in the Radiance array. It provides the mapping between the index along a dataset's *nWave* dimension and the actual wavelength. Not every scene contains every possible wavelength (see reason three below). The wavelengths for a particular image and slit are chosen from a fixed set which is provided in the **WavelengthGrid** dataset. **WavelengthGrid** is provided for reference and while it may be useful in for some work, the **Wavelength** dataset should be the primary source of wavelength information for users of the LP-L1G-EV product.

A wavelength is assigned for each index of the wavelength dimension of the Radiance dataset. The assignment continues to be non-uniform in Version 2 of the data but the simplifications in the processing have reduced variation between images and slits. For any element of the Radiance array the correct wavelength is in the Wavelength array at the corresponding (nSlit, nWavelength, nTime) element.

4.6 Using Wavelength Arrays

Understanding the organization of the Wavelength arrays and how to use them is key to using the gridded OMPS Limb data. Users of the data need to be aware of the non-uniform nature of the wavelength array and handle it in their codes accordingly. In general this means that software using the data needs to search the wavelength array for the index of the target wavelength for *each* slit-image being evaluated. For example, if a retrieval algorithm needs the radiance profile at 305nm then for each slit-image the Wavelength dataset will need to be searched for the index which might look something like this in Fortran: `minloc(abs(.305-WavelengthArray))`. That index is used to extract 1) the actual wavelength of the profile from the wavelength array and 2) the radiances which comprise the 305nm profile from the Radiance dataset.

In other words, at any given index into the spectral dimension of the Wavelength array the wavelength is not guaranteed to be constant across all slits-images. Subsection 4.7 shows an example of searching for a close wavelength and extracting the radiance profile at that wavelength in order to plot a radiance profile.

Dataset Name	Description	Dimensions	Units	Abbrv
Bandpass	Bandpass of the grid pixel. This array is not recommended for use.[a]	nTimes x nSlit x Wavelimit	microns	μm
Date	Date encoded in 32 bit integer. When formatted as a decimal number the date is encoded in the digits as YYYYMMDD	nTimes x nSlit	Unitless	NA
DateTimeUTC	Date string in Universal Coordinated Time. Format example is 2012-02-10T05:49:32.954987Z	nTimes x nSlit		
NumberOfPrimaryChannels	The number of valid indexes in the nWave dimension of a dataset. See Section 3.4 for details.	nTimes x nSlit	Unitless	NA
NumberOfTangentHeights	The number of tangent heights the G&C algorithm was able to extract.	nTimes x nSlit	Unitless	NA
Radiance	Radiance values combined and interpolated to the grid point.	nTimes x nSlit x nTH x nWave	Watt per meter squared per nanometer per steradian	$\mathrm{Wm^{-2}nm^{-1}sr^{-1}}$
SNR	Estimate of detector noise and *not* an estimate of random measurement uncertainty.	nTimes x nSlit x nTH x nWave	Unitless	NA
TangentHeight	Height above surface along normal to WGS84 ellipsoid.	nTimes x nSlit x nTH	kilometers	km
Wavelength	The wavelength corresonding to the corresponding index in the Radiance field.	nTimes x nSlit x Wavelimit	microns	μm
WavelengthGrid	The parent set of all wavelengths used for the wavelength dimension of the grid		microns	μm
WavelengthProfileQuality	These flags are depricated. They should not be used and are not described here.		unitless	NA

Table 3: Field names, description, dimensions, and associated units for GRIDDED_DATA group.

tab:gridunits

[a] The Bandpass array is only present for backwards compatibility and is not sufficiently accurate for science work.

4.7 Radiance Profile Example

RadProfile

A common type of plot to evaluate is the profile of radiances at a given wavelength vs altitude. An example of a radiance profile near 305nm is presented in Figure 7. The code listing demonstrates the key technique of searching for a wavelength in the data near the required 305nm and using the result of that search for further processing. Note that unlike the more complex bolide example (Example 14) here we are only concerned with a profile at a single image and so need only to identify the wavelength index for that one image. The Python code used to produce this Figure 7 is shown in Listing 2.

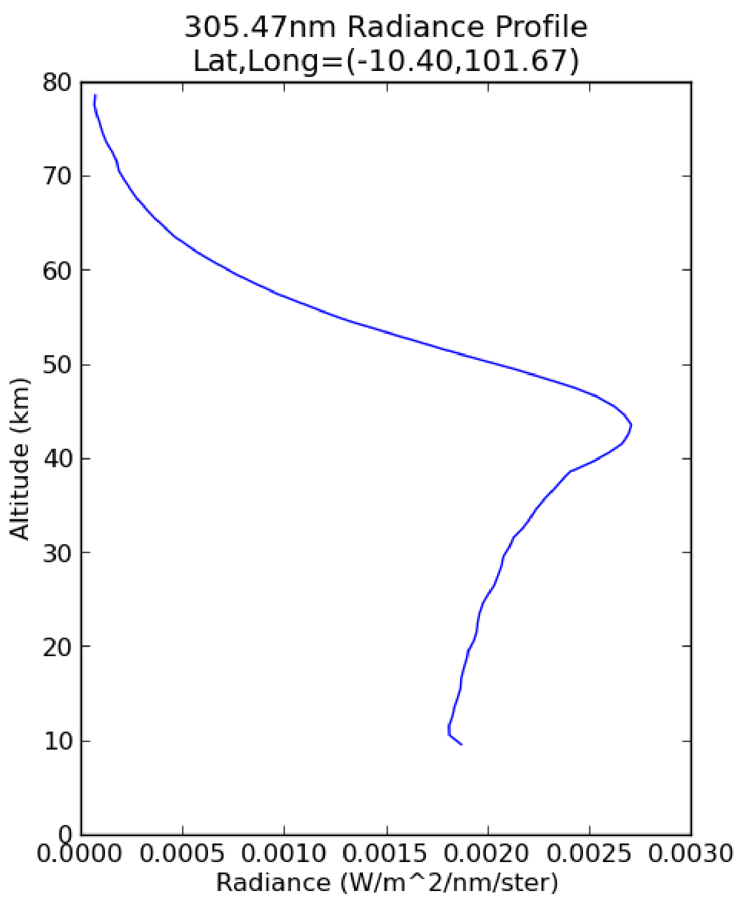

Figure 7: The radiance profile at 305nm, image 90. fig:Profile

```python
1  import h5py
2  import numpy
3  from matplotlib import pyplot
4
5  BolideOrbitFile = 'OMPS-NPP_LP-L1G-EV_v2.0_2013m0215t060054_o06752_2014m0416t135524.h5'
6
7  Slit = 2 # Right slit
8  TargetWavelength = .305 # microns
9  Event = 90
10
11 with h5py.File(BolideOrbitFile,'r') as fid:
12     WavelengthGrid = fid['/GRIDDED_DATA/WavelengthGrid'][...]
13     ClosestWavelength = WavelengthGrid[WavelengthGrid.searchsorted(TargetWavelength)]
14
15     Wavelength = fid['/GRIDDED_DATA/Wavelength'][Event,Slit,:]
16
17     TargetLocation = numpy.where(Wavelength == ClosestWavelength)[0][0]
18
19     RadianceRaw = fid['/GRIDDED_DATA/Radiance'][Event,Slit,:,TargetLocation]
20     Mask = RadianceRaw < -998
21     Radiance = numpy.ma.array(RadianceRaw,mask = Mask)
22     TangentHeight = fid['/GRIDDED_DATA/TangentHeight'][Event,Slit,:]
23     Latitude_45km = fid['/GEOLOCATION_DATA/Latitude_45km'][Event,Slit]
24     Longitude_45km = fid['/GEOLOCATION_DATA/Longitude_45km'][Event,Slit]
25
26 pyplot.figure(figsize=(5,6))
27 pyplot.xlabel('Radiance (W/m^2/nm/ster)')
28 pyplot.ylabel('Altitude (km)')
29 pyplot.title('{:4.2f}nm Radiance Profile\nLat,Long=({:4.2f},{:4.2f})'\
30     .format(1000*Wavelength[TargetLocation],Latitude_45km,Longitude_45km))
31 pyplot.plot(Radiance,TangentHeight)
32 pyplot.show()
```

st:Profile

Listing 1: Python program plot an OMPS Limb radiance profile at 305 nm.

Line 17 Search for the index of the closest wavelength to 305 nm using `numpy.where`. The result, **TargetLocations**, will be a an array of an array, hence the double index–[0][0]–used to extract the index.

Lines 20 & 21 Use the masked array facility to mask out those radiance values which are fill values, -999 in this case. The **plot** command will use the mask for both the radiances and the tangent heights to maintain the same ordered pairs.

4.8 Origin of Wavelength Arrays

Because of the central importance that wavelengths play in spectral data it is instructive to consider the orgin of the L1G wavelength arrays. The wavelength assignments are non-uniform for three reasons. The first is simply that the light is spectrally resolved via a prism which inherently produces a non-uniform wavelength spacing on the regularly spaced CCD pixels. The second is that bandwidth considerations prevent the entire 2D image on the CCD from being down-linked from the satellite and thus some wavelengths may be skipped. The selection of which pixels are down-linked is made by a reprogrammable table (referred to as the Sample Table). Parts of the spectra which are physically less interesting or are not useful due to instrumental effects (e.g. filter edges) are not down-linked. The Sample Table is programmable and subject to change during the mission and while this is expected to be a rare occurrence it is possible that a wavelength could appear or disappear during the mission. A history of Sample table changes is in Table 8.

The third reason is that the algorithm which makes the wavelength assignments is trying to produce a profile. If insufficient data (due to saturation or low signal level) are available in a particular profile to interpolate to a particular wavelength, then the gridding algorithm will not include that wavelength assignment for that measurement. Since this situation is scene-dependent, it can change during the course of an orbit. The wavelength assignments are in the Wavelength dataset described below. The assignment of wavelengths to the wavelength grid points is greatly simplified in Version 2 as compared to Version 1 which is expected to simplify the use of the LP-L1G-EV product in some cases.

Thus, for all wavelengths reported for a particular slit and image there will be at least one gridded radiance point.

4.9 Geolocation Data

The geolocation data group is show in Figure 8 with detailed descriptions of the datasets in Table 4.

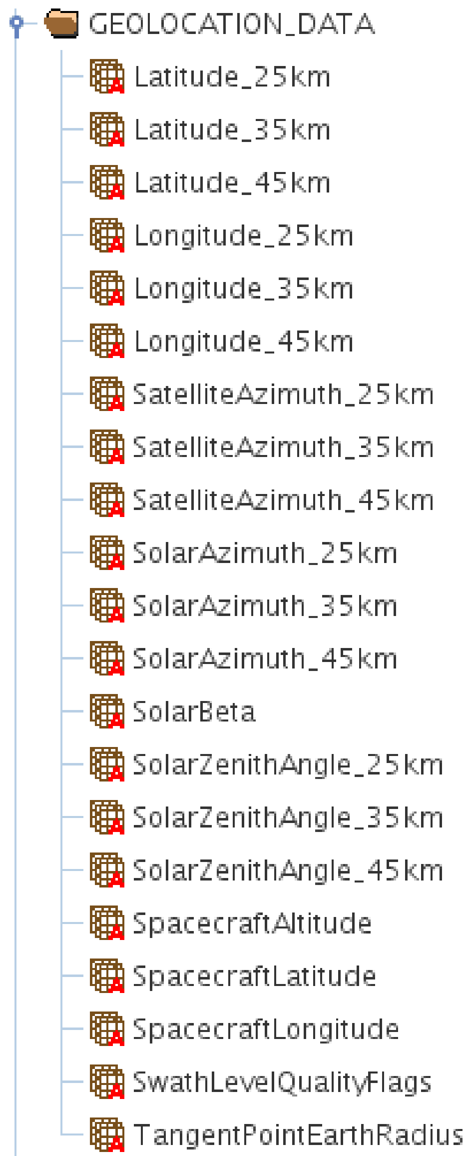

Figure 8: The GEOLOCATION_DATA group. fig:GEO

For the various azimuth fields 0 is defined as the direction of North. They are defined between -180 and 180 degrees. Positive azimuth is East of North.

4.10 Image Level Flags

An 'image', as used in this document refers to data collected across all slits during a particular (nominally 19 second) reporting period. Image level flags indicate instrument-level phenomena which apply to all altitudes and wavelengths (and possibly all three slits) of a specific image. In effect they

Dataset Name	Description	Dimensions	Units	Abbrv
Latitude_25km Latitude_35km Latitude_45km	The latitude of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees degrees degrees	
Longitude_25km Longitude_35km Longitude_45km	The longitude of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees degrees degrees	
SatelliteAzimuth_25km SatelliteAzimuth_35km SatelliteAzimuth_45km	The satellite azimuth of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees degrees degrees	
SolarAzimuth_25km SolarAzimuth_35km SolarAzimuth_45km	The solar azimuth of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees degrees degrees	
SolarBeta	The solar β angle.	nTimes	degrees	
SolarZenithAngle_25km SolarZenithAngle_35km SolarZenithAngle_45km	The solar zenith angle of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees degrees degrees	
SpacecraftAltitude	The spacecraft altitude above the WGS84 ellipsoid.	nTimes x nSlit	kilometers	km
SpacecraftLatitude SpacecraftLongitude	The latitude and longitude of the spacecraft ground point on the WGS84 elipsoid.	nTimes	degrees degrees	
SwathLevelQualityFlags	Flags describing various aspects of the measurement.	nTimes	unitless	
TangentPointEarthRadius	Radius of earth at tangent point.		kilometers	km

Table 4: Field names, description, dimensions, and associated units for GEOLOCATION_DATA group.

tab:geounits

Bits	Description
0-1	Mercury
2-3	Venus
4-5	South Atlantic Anomaly (SAA)
6-7	Mars
8-9	Jupiter
10-11	Saturn
12-13	Uranus
14-15	Neptune
16-17	Pluto+Charon
18-19	Moon (Earth's)
20	Attitude Maneuver in Progress
21	Non-nominal Attitude
22-23	spare
24	Solar Eclipse
25-31	spare

Table 5: Swath-Level Geolocation Flags for OMPS LP. Flags corresponding to a Celestial body indicate presence of that body in one of the three fields of view, see Table 6

SwathLevel

.

Value	Description
0	Not in field of view
1	In Left Slit
2	In Center Slit
3	In Right Slit

Table 6: Interpretation of 2-bit celestial object flags.

tab:Celestia

depend on the position and attitude of the satellite and not the tangent point of the profile. The link between a specific profile the relevant flags is the index in the *nTimes* dimension. For historical reasons the flag dataset is named SwathLevelQualityFlags instead of ImageLevelFlags.

Tables 5 and 6 describe bits dedicated to flagging a celestial body visible in a given slit (the small angle subtended by celestial bodies, including the moon, guarantee that any particular body can be in only one slit at a time); relative intensity of SAA particle hits on an OMPS sensor; and the likely presence of solar eclipse conditions.

4.11 South Atlantic Anomaly (SAA) Flags

Passage through the South Atlantic Anomaly is flagged at the image level because the effect on the CCD of charged-particle hits (primarily protons of solar origin trapped in the earth's magnetic field) depends only on the spacecraft latitude, longitude, and altitude. While individual pixels may be affected, causing errors in the number of counts for particular FOVs in a particular frame, the geolocation of those *pixels* is irrelevant to the estimate of the probable number of hits to the CCD; only the spacecraft (and therefore instrument) geolocation determines the values of these flags. The link between a particular radiance profile and the SwathLevelFlags is the image number.

The SSA map was created using 'doors closed' dark data and shows SAA intensity over a geographic region. The intensity of the SAA effect is defined as the product of the number of particle hits and the energy of the particle hits. The Figure 9 shows contours of SAA intensity corresponding to the thresholds used to construct the flags (Table 7).

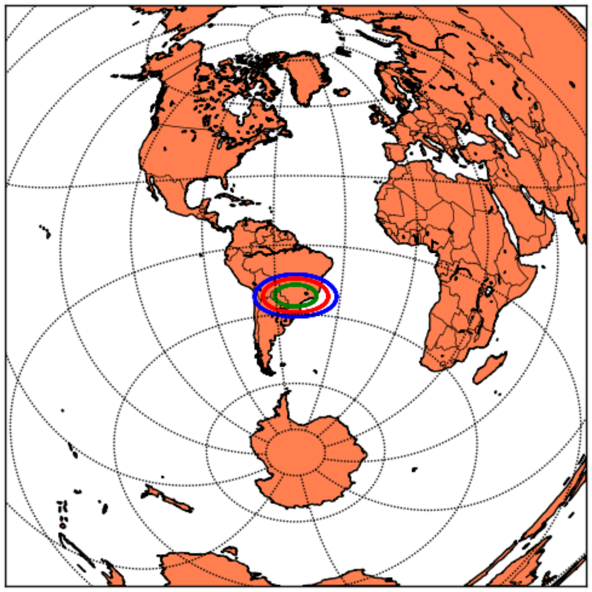

Figure 9: The South Atlantic Anomaly showing contour lines of particle hit intensity The energy of the particles is not uniform a fact which is taken into account in the SAA flags. `SAA:Bounding`

There are four flag states possible within the SAA flag, see Table 7 for their descriptions.

Bits 4-5 in Binary (Decimal)	Description
00 (0)	$<$ 5% of nominal maximum SAA intensity
01 (1)	5-40% of nominal maximum SAA intensity
10 (2)	40-75% of nominal maximum SAA intensity
11 (3)	$>$ 75% of nominal maximum SAA intensity

Table 7: The SAA flag consists of bits 4 and 5 (0 based) of the first byte of the 32-bit SwathLevelQualityFlags dataset. Intensity is defined as particle energy $\times$ number of hits per energy bin `tab:SAAbits`

4.12 SAA Example

The cleanest way to use the SAA flag is to write a computer program to read in the SwathLevelQualityFlags and perform a bit shift and mask. Example code and output for this in Python is presented. Similar operations are available in Fortran and IDL.

Line 24 This line does the key work. The `>> 4` shifts the two SSA bits into the lowest order bits and then `& 0b11` clears the higher order bits. The result is any array of integers in the decimal range [0,3].

```
1  from __future__ import print_function, division
2  import h5py
3  import numpy
4  # Sorting file names creates output in time order
5  Filenames=sorted(["OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t001624_o05415_2014m0411t170331.h5"
6                    "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t084351_o05420_2014m0411t170340.h5"
7                    "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t171119_o05425_2014m0411t170335.h5"
8                    "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t015753_o05416_2014m0411t170227.h5"
9                    "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t102521_o05421_2014m0411t170248.h5"
10                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t185249_o05426_2014m0411t170355.h5"
11                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t033923_o05417_2014m0411t170353.h5"
12                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t120650_o05422_2014m0411t170356.h5"
13                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t203418_o05427_2014m0411t170410.h5"
14                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t052052_o05418_2014m0411t170321.h5"
15                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t134820_o05423_2014m0411t170352.h5"
16                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t221548_o05428_2014m0411t170453.h5"
17                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t070222_o05419_2014m0411t170303.h5"
18                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t152949_o05424_2014m0411t170423.h5"
19                   "OMPS-NPP_LPEV-L1B-p000_v2.0_2012m1113t235717_o05429_2014m0411t170334.h5"
20
21 for f in Filenames:
22     with h5py.File(f,'r') as infid:
23         SwathLevelQualityFlags  = infid['/GEOLOCATION_DATA/SwathLevelQualityFlags'][...]
24     SAA = (SwathLevelQualityFlags >> 4) & 0b11  # Shift all words right by 4 bits
25                                                 # and mask to keep 2 Lower order bits
26     print('SAA Flags for Orbit Start Time (UTC)',f[37:40]+':'+f[40:42]+':'+f[42:44])
27     print(''.join([str(x) for x in SAA]))
```

Lines 26,27 These format the output. In particular, line 27 prints the output values (0-3) without intervening spaces to produce compact output,

```
SAA Flags for Orbit Start Time (UTC) t00:16:24
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t01:57:53
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t03:39:23
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t05:20:52
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t07:02:22
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t08:43:51
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t10:25:21
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t12:06:50
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t13:48:20
0000000000000000000000000000000000000000000000000000000001111111111111111111110000000000
SAA Flags for Orbit Start Time (UTC) t15:29:49
0000000000000000000000000000000000000000000011111111112222222222222222221111111111100000
SAA Flags for Orbit Start Time (UTC) t17:11:19
0000000000000000000000000000000000000001111111112222223333333333222222111111111000000000
SAA Flags for Orbit Start Time (UTC) t18:52:49
0000000000000000000000000000000000000001111111111111111111111111111110000000000000000000
SAA Flags for Orbit Start Time (UTC) t20:34:18
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t22:15:48
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SAA Flags for Orbit Start Time (UTC) t23:57:17
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

OP:SAAOutput

4.12.1 Solar Eclipse Flag

For OMPS Limb, exactly where the shadow falls the earth's surface may not be a useful measure of how sunlight may be affected for measurements during an eclipse. Therefore, the eclipse algorithm sets a flag at in SwathLevelQualityFlags based on the time rather than the specific path of the eclipse. This flag is intended as a qualitative warning for OMPS Limb Earth view and solar calibration measurements. Bit 24 of the SwathLevelQualityFlags elements indicates a possible solar eclipse during this image somewhere on Earth (generally relevant only on daytime side of Terminator): 0 indicates, no eclipse; 1 indicates eclipse.

4.12.2 Aperture (Gain) Flags

As described in the Limb Algorithm Theoretical Basis Document the Limb instrument uses two different apertures (large and small) via two different optical paths. These data are consolidated into the single spectral profile presented in the L1G product. During consolidation the version 2 ground processing software preferentially uses large aperture data below 495 nm and small aperture data above 495 nm wavelength. The benefit of this discrimination is that systematic errors associated with the optical path remain consistent along the profiles.

To achieve complete large-small aperture discrimination at the ground processing step it is necessary that the Sample Table loaded onto the instrument be designed consistent with this goal. Not all Sample Tables used meet this criterion. In particular, STBs used earlier in the mission did not. In order to allow the end user to detect cases where the different aperture data appears along a profile a flag is provide for each pixel indicated which aperture was used.

The flags are contained in the dataset **GRIDDED_DATA_SUPPLEMENTAL/PixelFlag**. This is a packed array of bit flags. The only flags described in this document are those necessary to understand the aperture in use. The aperture bit flags use four bits which can be extracted using a shift and mask operation: Right shift by 3 bits and mask by 3 (decimal, 11 binary). If the result is even (0 or 2) then small aperture was used, if the result is odd (1 or 3) than large aperture was used.

Figure 10: Map of the aperture selection for a single image for gridded data. From top to bottom the three plots are left, center, and right slits. The red show pixels which were interpolated from large aperture and the green indicates where small aperture data was used. This orbit was measured using an older sample table. The green at low altitudes near 350 nm 425 nm illustrate the case when the ground processing software needs to use small aperture data for UV wavelengths. fig:Aperture

4.13 Metadata

4.13.1 Input Pointers

The product file has a group called **Input Pointers**. It contains information about how the data processing proceeded for the file in question. In general this is of little interest to the end user. However, its contents may be useful in specific situations when requesting help on the product. Figure 11 shows the TreeView of the input pointers. The dataset **ControlFileContents** is a string containing a data structure in the YAML data serialization language.

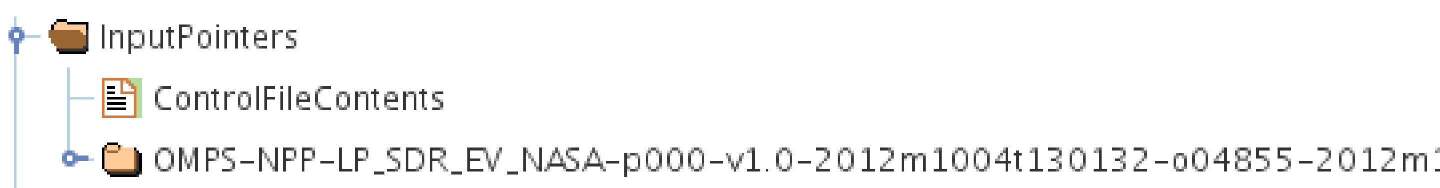

Figure 11: The InputPointers group. fig:InputPoi

4.13.2 Digital Object Identifier

The data are provided with a Digital Object Identifier (DOI). This is form of a World Wide Web address. It can be used to get updated information about the product from the producers web site.

Figure 12: The DigitalObjectIdentifier dataset. fig:DOI

The DOI is contained in a top level character dataset. The dataset is encoded in JavaScript Object Notation (JSON) which is a data serialization language which is comparatively simple for humans to read. In addition, parsers exist in many languages so that software can automatically parse the string and resolve its different components.

The DOI for the product consists of two components. One is the DOI itself. The second is the DOI authority for resolving the DOI into a Web address, also known as the Landing Page. Figure 13 shows an example of the value of the DigitalObjectIdentifier dataset.

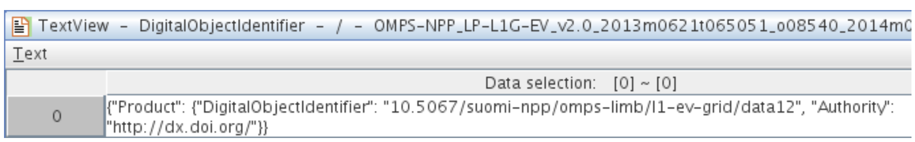

Figure 13: An example of the digital object identifier dataset as viewed in HDFView. fig:DOIValue

The DOI is used by forming a web address loading it in a web browser. The address corresponding to dataset in Figure 13 is `http://dx.doi.org/10.5067/suomi-npp/omps-limb/l1-ev-grid/data12`

5 Instrument and Satellite Operations

The Suomi NPP satellite is occasionally commanded to execute maneuvers which could interrupt nominal limb earth view measurements or cause the instrument to point in an unusual direction while executing nominal earth view measurements. Furthermore, the OMPS's operation can change from orbit to orbit. As discussed above, the nominal earth view sample table can change because a better one is developed. Also, the instrument is regularly (and irregularly, on an *ad-hoc* basis) commanded to run in a different measurement mode which takes *non-nominal* earth view data (i.e. uses a special sample table) or no limb earth view data at all. Additionally, communication failures can cause data to be incomplete or lost altogether.

The impact of this variation on the user is expected to be minimal. An important consideration is that software using the L1G data files should not 'hard code' the sizes of the arrays, the correspondence between wavelength index and wavelength, or between altitude index and altitude. In the case when no data are available no orbital L1G file is released.

When interpreting results from the OMPS data it can sometimes be useful to know the corresponding mode of the instrument or satellite. For example, an unexpected discontinuity between orbits should be checked against changes to satellite or instrument operations. It is not practical to provide a complete accounting of the operating mode for all orbits in this document.

The volume of data and the fact that any static table would be out-of-date as soon as it was published would undermine the utility of such a table. Instead, an overview is presented here while an authoritative account is provided on the OMPS website. The orbit ranges in Table 8 are the ranges during which the respective sample table was loaded on the instrument for nominal earth view measurements. For the first 3737 orbits early operations type activities were undertaken making the catalog of earth view orbits too complex for this document.

Orbits	**Load Date**	**End Date**	**Name**	**Description**
1-3737	10/28/11	02/06/12	Various	Mix of early operations Sample Tables
3738-4658	02/06/12	09/20/12	84.5	Minor smear pixel revision to operational table
4659-10788	09/20/12	11/26/13	0.4	Minor revision to move wavelength registration columns
10789-11612	11/26/13	01/23/14	0.5	First revision for improved spectral coverage
11613-12010	01/23/14	02/20/14	0.6	Second revision for spectral coverage
12011-13101	02/20/14	05/08/14	0.7	Third revision for spectral coverage
13102-current	05/08/14	still current	0.8	Small changes to improve IR coverage

Table 8: Sample Table Upload History. The orbit ranges indicate the orbits for which the sample table was the nominal earth view sample table. Before orbit 3738 the instrument changed operating modes too frequently for it to be practical to include a description in this document. After orbit 3738 tests are still occasionally run (at least once per week) interrupting the nominal earth view measurements. tab:STBChang

On both a regular (weekly) and also irregular basis the instrument is put into a mode in which nominal earth view data are not collected. This can lead to either missing orbits or earth view data using a alternate sample table. A notable example of this is the weekly Full Frame data in which all pixels on the CCD are downlinked but only 32 (instead of 160 or 180) images are captured during the day side pass. A gridded product is produced for these data as with nominal earth view, but the wavelength and altitude coverage will be greater at the expensive of sparser along track (latitude) coverage.

6 Chelyabinsk Bolide Example

helyabinsk

To illustrate the use of OMPS limb data an image of the Chelyabinsk bolide dust cloud was generated from a single orbit of data. On 15 February 2013 a bolide (or meteor) exploded 23.3km above Chelyabinsk, Russia. It has been shown that dust injected into the atmosphere by the bolide was detectable by the OMPS Limb L1G instrument. GRL:GRL50788 [1] This image can be seen clearly even in just one orbit of OMPS Limb data, see Figure 14.

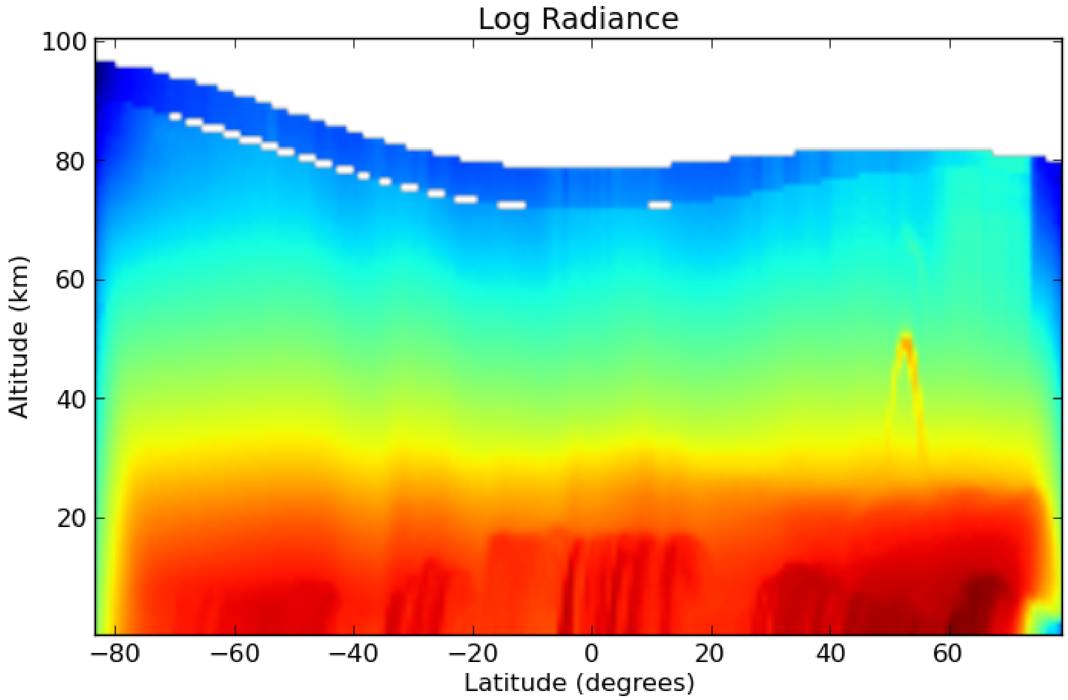

Figure 14: OMPS Limb L1G data at approximately 724 nm, showing the Chelyabinsk bolide dust trail from Suomi NPP orbit 6752 on 15 February 2013. The dust is detected at about 50km high, 55 degrees North latitude.

fig:BolideEx

Line 11 The wavelength grid is loaded. This array contains the complete set of wavelengths used to grid the data. For any given spectra some (possible improper) subset of the wavelengths will be reported out. These are contained in the Wavelength dataset.

Line 12 Identify the wavelength in the superset closest to the target wavelength of 724 nm.

Line 16 Locate all the places in the 2D Wavelength array for radiances actually reported out at 724 nm. The numpy *where* function returns two list of indexes–one for each dimension–unlike the similarly named function in IDL. Note also, that the use of the equality (==) test, while generally discouraged in numerical codes, works here because the values of Wavelength were copied bit-for-bit from **WavelengthGrid** when the L1G data file was created.

Line 19 Use the array of TargetLocations to extract the desired event (TargetLocations[0]) and wavelength (TargetLocations[1]) from the Radiance array. The slit is specified by Slit, so the result is a set of 2D array of radiances, altitude x event number.

Line 23 The fill value used in this data is -999, so the mask marks all those arrays which are fills (radiances are never negative.) The Matplotlib plotting software will automatically choose white for the mask elements which are True. (Note that the mask here has the opposite sense as the mask used in Fortran 90 where the values used are the True values in the mask.)

The latitude axis of Figure 14 is, due to the polar orbit, also essentially a time axis. The radiance values at each latitude are from different 19 s reporting periods. Not all possible wavelengths are reported out in every reporting period which has implications for tracking specific wavelengths across multiple reporting periods.

The code which generated the figure is shown in Listing 1. It demonstrates a basic use of the Limb Version 2 L1G data. One unusual feature of this example is that it incorporates radiance data from each vertical radiance profile in the orbit (at the wavelength closest to 724 nm). For example, the closest possible wavelength to 724nm in the Version 2 **WavelengthGrid** is 728 nm, however due to scene variability (e.g. saturation) a particular measurement might not have values at 728 nm and thus it would not be reported out and the closest wavelength would be 719 nm. A retrieval might be written to 'choose the closest available'. For the bolide image the 'skip if missing' approach was used because a scene at a constant wavelength was desired.

References

L:GRL50788 [1] Nick Gorkavyi, D. F. Rault, P. A. Newman, A. M. da Silva, and A. E. Dudorov. New stratospheric dust belt due to the Chelyabinsk bolide. *Geophysical Research Letters*, 40(17):4728–4733, 2013.

`$Revision:: 41     $`

```python
import h5py
import numpy
from matplotlib import pyplot

BolideOrbitFile = 'OMPS-NPP_LP-L1G-EV_v2.0_2013m0215t060054_o06752_2014m0416t135524.h5'

Slit = 2 # Right slit
TargetWavelength = .724 # microns

with h5py.File(BolideOrbitFile,'r') as fid:
    WavelengthGrid = fid['/GRIDDED_DATA/WavelengthGrid'][...] # 1-D slice
    ClosestWavelength = WavelengthGrid[WavelengthGrid.searchsorted(TargetWavelength)]

    Wavelength = fid['/GRIDDED_DATA/Wavelength'][:,Slit,:] # 2-D slice

    TargetLocations = numpy.where(Wavelength == ClosestWavelength)

    Radiance = fid['/GRIDDED_DATA/Radiance'][...] #4-D slice: event x slit x alt x wave
    RadianceImage = Radiance[TargetLocations[0],Slit,:,TargetLocations[1]].transpose()
    TangentHeight = fid['/GRIDDED_DATA/TangentHeight'][...]
    Latitude_45km = fid['/GEOLOCATION_DATA/Latitude_45km'][:,Slit]

MaskedRadianceImage = numpy.ma.array(RadianceImage,mask=RadianceImage < -998)
pyplot.imshow(numpy.log(MaskedRadianceImage),origin='lower',
              extent=[Latitude_45km.min(),Latitude_45km.max(),
                      TangentHeight.min(),TangentHeight.max()])

pyplot.title('Log Radiance')
pyplot.ylabel('Altitude (km)')
pyplot.xlabel('Latitude (degrees)')
pyplot.show()
```

Listing 2: Python program used to create the image. The latitudes on the abscissa are created by specifying the min and max values and dividing the axis up into equal parts. This is valid to the extent that the latitude increases linearly with event. Since NPP is inclined from a true polar orbit this is only approximate.